GLOBAL THERMAL METAMORPHISM ON THE EUCRITE PARENT BODY

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Abstract. We made a petrologic study of 14 eucrites. The eucrites have not only igneous textures but also metamorphic textures formed by post-crystallization processing, including brecciation, recrystallization, and melting. Abundant augite grains and abnormally thick augite lamellae in the recrystallized portions of some eucrites could be secondary products formed during thermal metamorphism. Final equilibrated temperatures, estimated by two-pyroxene geothermometer, range from ~720 to 880 °C, suggesting a prolonged period of metamorphism. This thermal event could have been global in scale and might have taken place after the initial differentiation and production of a basaltic crust on the parent body.

Introduction. Eucrites, the most ancient basalts in the solar system, were probably excavated from Vesta [1]. After volcanism, eucrites experienced shock and thermal metamorphism [e.g. 2-7]. Takeda and Graham [3] suggested that eucrites form a metamorphic sequence from type 1 (the least metamorphosed) to type 6 (the most metamorphosed). We studied 14 type 4-6 eucrites by optical microscopy, SEM, and EPMA. Based on textural observations and two-pyroxene thermometry, we inferred the conditions of thermal metamorphism and examined the role of metamorphism and impact played in the evolution of the eucrite parent body (EPB).

Results. Monomict eucrites and crystalline eucritic clasts in polymict eucrites show not only igneous textures but also metamorphic textures formed by post-crystallization processing. Recrystallized rocks (RR) are the most common metamorphic textures in eucrites (Table 1). The RRs often show relict igneous texture. Typically, there is a continuum between the RR and the pristine igneous texture within an individual eucrite. The RRs might have been formed by recrystallization of the pristine igneous portions, perhaps aided by weak brecciation and/or shock deformation. The clouding caused by precipitation of tiny opaque minerals [4], widespread in the pristine pigeonites is rare in the RR. Aggregates of transparent granulitic pyroxenes coexisting with large chromite and/or ilmenite grains (~60 μm in diameter) [5,6], observed in Lakangaon, Millbillillie, and Jonzac, might have formed by a similar process. Emaville has an exceptionally fine-grained RR, but still has relict igneous texture. Textures of the clastic matrices of eucrites vary from detrital to completely recrystallized. Millbillillie and Y74356 have completely recrystallized clastic matrices (RCM) consisting of equant grains with smooth boundaries meeting at roughly 120° [5,7]. The matrices of Jonzac and Haraiya are only slightly recrystallized. Kirbyville is a cataclastic monomict breccia with a completely unrecrystallized matrix. The clasts of Kirbyville consist of monomict breccias with slightly RCM. EET92025 and EET92027 are post-metamorphic monomict breccias containing clasts of crystalline impact melt (CRM) breccias in which pyroxenes are completely equilibrated. HOW88041 is a complex breccia consisting of crystalline melt (CRM) and granulitic breccia (RR-RCM); this rock could have been formed by two separate shock events during thermal metamorphism.

Generally, augites in type 4-6 eucrites occur as thin exsolution lamellae (~3 μm in thickness) in the primary pigeonite [3]. Primary augites are rare in eucrites [8]. However, the RRs are often composed of pigeonite and a high abundance of rounded augite (<60 μm in apparent diameter). The RR and the RCM often have abnormally thick augite lamellae (<50 μm in thickness), which are not common in pristine igneous portions. It seems likely that these augites formed by recrystallization at a temperature below the two-pyroxene solvus, after the shock event. Based on the pyroxene Ca-thermometer of Kretz [9], final equilibrated temperatures vary from ~720 to 880 °C (Fig. 1), much lower than the igneous crystallization temperatures of eucrites (~1200 °C). In contrast to the pyroxene closure temperatures of the eucrites, those of cumulate eucrites cover a wider range (Fig. 1). There is no simple relationship between petrologic types of eucrites and the closure temperatures of augites.

Discussion. Miyamoto *et al.* [10] suggested that type 5 eucrites formed by equilibration of type 2 eucrites; the equilibration of the pyroxene grains occurred during < 1 Ma at 1000 °C. In contrast, recrystallization of the brecciated portions may be several orders of magnitude faster than the time scale of the homogenization of the pigeonites at ~1000 °C [11]. It is possible that the primary pigeonites had already equilibrated when the shock and brecciation experienced by many eucrites took place. The presence of the transparent granulitic pyroxenes may be an evidence of shock events during the thermal metamorphism [5, 6]. Because the closure temperatures obtained by Kretz [9] are lower than 1000 °C used by Miyamoto *et al.* [10], we conclude that the duration of the metamorphism was much longer than the estimation of 1 Ma [10], perhaps as long as 100 Ma. This suggests that internal heating was the major source of thermal metamorphism of the EPB. This hypothesis supports the presence of a number of pristine but strongly metamorphosed eucrites (basalts). However, shock, brecciation, and melting events also took place during the global thermal metamorphism.

METAMORPHISM OF EUCRITES; Yamaguchi et al.

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Table 1. Petrographic and mineralogical characteristics of the eucrites

	primary pyroxene		overall	transparent
	petrologic type [3]	feature	metamorphic textures	granulitic pyroxene*4
Stannern	4	cloudy	RR*1, RCM*2	yes ?
LEW86001(clast)	4	cloudy	RR	yes ?
Haraiya	5	cloudy	RR, RCM	no
Emaville	5	(clear)	RR	yes ?
Lakangaon	5	cloudy	RR	yes
PCA91179	5	clear	RR	no
LEW88005(clast)	5	clear	RR	no
EET92025	5	clear	CRM*3	no
EET92027	5	clear	CRM	no
HOW88401	5	cloudy-dusty	RR-CRM	yes
Y74356	5	cloudy-dusty	RR-CRM	yes
Kirbyville	6	cloudy	RCM	no
Jonzac	6	cloudy	RR, RCM	yes
Millbillillie	6	cloudy	RCM,CRM,RR	yes ?

*1 RR: recrystallized rock. *2 RCM: recrystallized clastic matrix. *3 CRM: crystalline melt.
*4 Aggregate of clouding-free equant shaped pyroxene coexisting with large chromite and/or ilmenite [4,5].

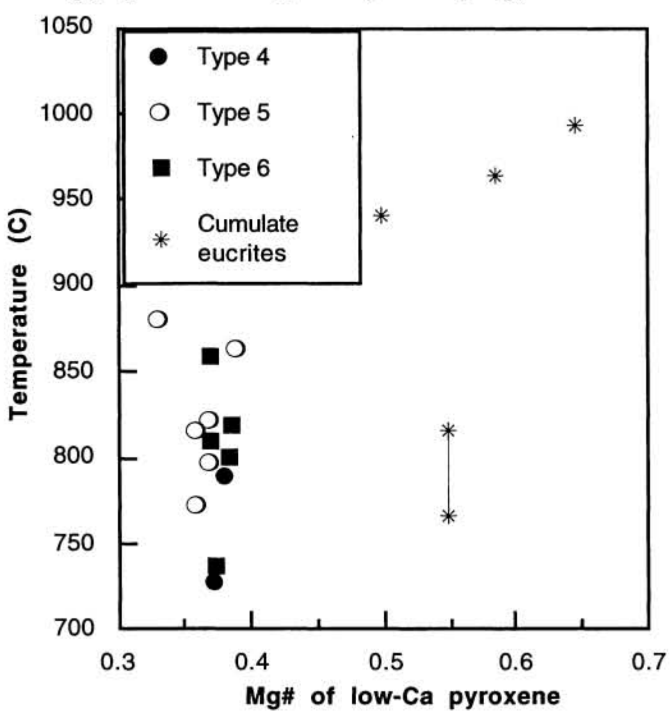

Fig.1. Pyroxene equilibration temperatures of eucrites plotted against the Mg#=Mg/(Mg+Fe) of the low Ca-pyroxene. The temperatures of cumulate eucrites were calculated from data of Takeda *et al.* [12] and Harlow *et al.* [13].